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AUTOMATIC COLLISION AVOIDANCE SYSTEM USING THE CONCEPT OF BLOCKING AREA

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Abstract: The authors propose an algorithm for automatic collision avoidance system for ships. The automatic collision avoidance system is one of important functions comprised in automatic navigation system. The concept of inherent blocking area is introduced as a parameter to evaluate collision risk among ships. Contents of blocking areas is defined with the parameters of ship length, breadth, relative speed and relative angle between courses. Numerical simulations using proposed algorithm were carried out with three types of ship such as container ship, VLCC and general cargo ship which have different principal particulars. Results of the simulation show that the proposed system works well for head-on, crossing and overtaking conditions for combination of these ships. *Copyright © 2003 IFAC*

Keywords: Automatic systems, Fuzzy inference, Manoeuvrability, Navigation systems, Ship control

1. INTRODUCTION

Navigational safety is highly demanded in order to prevent marine accidents and introduction of an automatic navigation device is one of solution of such a problem. In order to realize the automatic navigation device which does not need human operation, much information concerning not only own ship but other ships surrounding own ship is required. Recently precision of positioning using GPS becomes considerably better and discussion about mandatory installation of Automatic Identification System (AIS) for ships are in progress on the International Maritime Organization (IMO). Using these devices, each ship will be able to obtain her own position exactly and also easily derive information about other ship's position, heading, speed and so on.

The authors propose an algorithm for automatic collision avoidance system for ships. The automatic collision avoidance system is one of important functions comprised in automatic navigation system and there are a lot of studies about the system (Hara and Hammer, 1993) (Hasegawa and Fujita, 1993) (Kose *et al.*, 1997) (Kijima and Furukawa, 2001) (Lee and Rhee, 2001). *DCPA* (distance of closest point of approach) and *TCPA* (time to closest point of approach) are often used as parameters for evaluating degree of collision risk. In this paper, the concept of inherent blocking area is introduced as a parameter to evaluate collision risk among ships instead of *DCPA* and *TCPA*.

Numerical simulations assuming several encounter situations of two ships in collision risk were carried out to confirm validity of the presented automatic collision avoidance system. Three types of ship are utilized in the simulation study such as container ship, VLCC and general cargo ship which have different principal particulars.

2. CONCEPT OF THE BLOCKING AREA

The concept of the blocking area is introduced to evaluate collision risk among ships. The blocking area concept is originally proposed to evaluate a density distribution of ship trajectories surrounding own ship (Fujii *et al.*, 1966). Arimura et al. (Arimura *et al.*, 1994) classified the blocking area into four classes such as "Collision area", "Critical collision area", "Safety blocking area" and "Blocking area with space" depending on the density distribution. "Collision area" and "Critical collision area" represent close domain which is located near own ship. Then the authors decided to utilize "Safety blocking area" and "Blocking area with space" as a parameter to evaluate collision risk with other ships. Hereafter, those domains are simply called as "Blocking area" and "Watching area" respectively.

Both domains are shown in Fig.1. The broken line indicates the watching area and the solid line represents the blocking area. Existing ship in the watching area is regarded as target ship which should be watched out for by own ship. When the watching area of the target ship invades the blocking area, own ship should decide whether she will change or keep her course.

Shape of the blocking area is modeled as combination of two ellipses which are defined using R_{bf}, R_{ba} and S_b as shown in Fig.1. R_{bf} and R_{ba} indicate longitudinal radius of the blocking area in fore and aft domains respectively and S_b is common transverse radius in both domains. Estimation formulae for these parameters are proposed by Arimura et al. (Arimura *et al.*, 1994) as follows,

$$\left.\begin{aligned} R_{bf} &= L + (1+s)T_{90}U, \\ R_{ba} &= L + T_{90}U, \\ S_b &= B + (1+t)D_T, \end{aligned}\right\} \qquad (1)$$

where, L, B & U are ship length, breadth & speed, T_{90} is the time to 90 degrees heading, D_T is the tactical diameter and s & t are coefficients to consider influence of encounter situation.

Though T_{90} and D_T of own ship can be easily obtained, it is usually difficult to know values of these parameters for other ships. The authors used prediction formulae (Kadono and Yamasaki, 1978) to estimate T_{90},

$$T_{90} \simeq (0.67/U) \cdot \sqrt{A_D^2 + (D_T/2)^2}, \qquad (2)$$

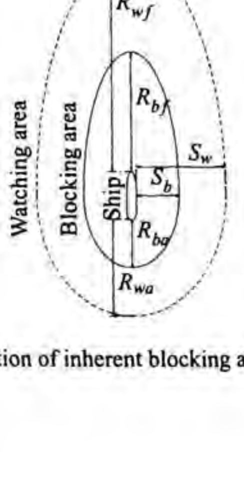


Fig. 1. Definition of inherent blocking area

where A_D represents the advance. Values of A_D and D_T can be estimated using following approximate formulae (Arimura *et al.*, 1994),

$$\left.\begin{aligned} \log(A_D/L) &= 0.3591 \log U_{kt} + 0.0952, \\ \log(D_T/L) &= 0.5441 \log U_{kt} - 0.0795, \end{aligned}\right\} \qquad (3)$$

where U_{kt} is ship speed represented in knots.

The parameters which provide shape of the watching area are obtained with following equations.

$$\left.\begin{aligned} R_{wf} &= L + 2(R_{bf} - L), \\ R_{wa} &= L + 2(R_{ba} - L), \\ S_w &= B + 2(S_b - B), \end{aligned}\right\} \qquad (4)$$

where R_{wf}, R_{wa} and S_w are longitudinal radius of the watching area in fore and aft domains and common transverse radius as already shown in Fig.1.

When a person make a judgment to avoid collision with other ships, the countermeasures should be changed depending on encounter situation. The authors represent such a difference in judgment of collision avoidance countermeasures using the parameters s & t appeared in equation (1) of which values are equal to 1 in normal operation.

On head-on situation, the target ship comes toward own ship from the front. Then it is important to watch out for a bow direction principally. The authors decided to elongate the longitudinal radius of the blocking area in bow domain depending on relative speed between own and target ships as shown in Fig.2 (a) with thick solid line. Elongation of the longitudinal radius is realized by changing value of the parameter s. As for the transverse direction, same value for S_b in normal operation is used. Following equations indicate values of the parameter s & t on head-on situation,

$$s = 2 - \Delta U / U_1, \qquad t = 1, \qquad (5)$$

where ΔU is relative speed represented by $U_1 - U_2$ and U_1 & U_2 are speeds of own & target ships.

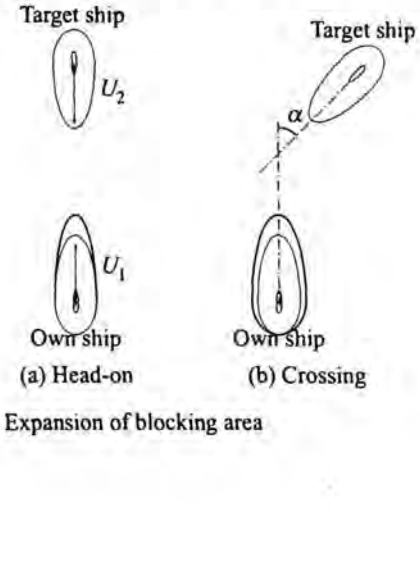


Fig. 2. Expansion of blocking area

On crossing situation, values of s & t are changed depending on relative angle between own course and target ship's course, because precaution in flank is important on crossing situation and degree of importance is different by the angle. The parameters s & t on crossing situation are given as follows,

$$s = 2 - \alpha/\pi, \qquad t = \alpha/\pi, \tag{6}$$

where α is relative angle between course of both ships.

On overtaking situation, it is expected that precaution in bow direction is important same as head-on situation. However, relative speed between overtaking ship and overtaken ship is ordinarily small and content of the blocking area in bow domain is sufficiently larger compared with that in stern domain. Then the authors decided not to change content of blocking area. So the parameters s & t on overtaking situation are given as follows,

$$s = 1, \qquad t = 1. \tag{7}$$

3. PROCEDURE OF JUDGMENT FOR COLLISION AVOIDANCE

Utilizing the blocking area defined in previous section, procedure of judgment for collision avoidance is examined. The navigation phase in the procedure is categorized into following three phases; (1) Normal navigation, (2) Evasive navigation, and (3) Return navigation.

The first phase represents normal navigation in original speed on original course. On this phase, own ship investigates motion of ships which exist in circumference continuously and estimates contents of the watching area of the target ships. Once overlap of the watching area of own and the target ships occur, it is recognized that collision risk is rising and it is examined that own ship should change route or not. If own ship is regarded as the give-way vessel and own blocking area wrap over the watching area of the target ship, navigation phase is move on to the second phase.

On the second phase, a ship does an action of evasion to avoid collision with other ships. When own ship starts evasive navigation, three virtual ships which have same speed and heading as own ship are introduced in order to find suitable course to avoid collision. Simultaneously, blocking area is set for each virtual ship. They are noted as A_0, A_1 and A_2 as shown in Fig.3. Positions of these virtual ships are mentioned later.

After the evaluation of content of overlapped area of own and target ship's blocking area, the virtual domain which has the smallest overlapped area in the three and which has the smallest course change angle is adopted as the objective area where own ship should bound in order to avoid collision. Then own ship will begin to change her course. When overlap of the blocking area disappears, it is evaluated that safety of navigation of own ship is secured. Then ship begins to return toward her original course. This motion is defined as the third phase.

On head-on situation, first virtual ship, noted with subscript '0' in Fig.3 (a), is located on the extension line of the original course. Distance $\overline{GG_0}$ which indicates between the center of gravity of own ship, G, and the virtual ship, G_0, is defined as follows,

$$\overline{GG_0} = 3UT_{90}. \tag{8}$$

Equation (8) means that $\overline{GG_0}$ is roughly three times of the distance that a ship go along by ship speed U for time T_{90}. The second and the third virtual ships noted with subscript '1' and '2' are arranged on the arc of radius $\overline{GG_0}$ in an equal interval ξ_h. In this paper, we adopted 15° as the value of ξ_h on head-on situation.

On crossing situation, the virtual ship 0 is positioned on the line which connects the center of gravities of own ship and the target ship as shown in Fig.3 (b). Value of $\overline{GG_0}$ is equal to $3UT_{90}$ same as head-on situation. Then the virtual ship 1 and 2 are arranged in an equal interval ξ_c which is equal to 20° in this paper. It is expected that ship speed drops as the course change angle becomes larger. Therefore, the distance between the own ship and virtual ships, $\overline{GG_1}$ & $\overline{GG_2}$, are simply shortened as follows,

$$\overline{GG_1} = \frac{2}{3}\overline{GG_0}, \qquad \overline{GG_2} = \frac{1}{3}\overline{GG_0}. \tag{9}$$

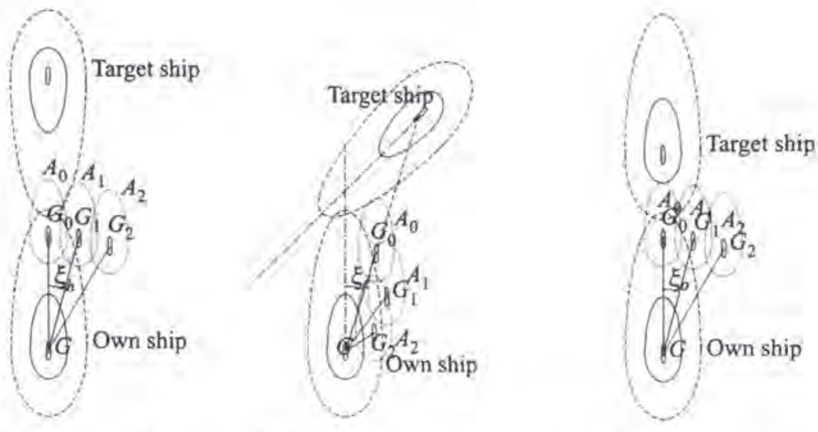
On overtaking situation, the virtual ships are located same as head-on situation but angle denoted with ξ_o between courses of each ship is different. ξ_o is equal to 10° on overtaking situation which is less than that on head-on situation.

A rudder angle which is required to lead a ship to new route smoothly and swiftly is obtained using fuzzy inference because there are many parameters which should be taken into account. Detail of procedure of steerage is shown in the previous paper (Kijima and Furukawa, 2002).

4. THE EVALUATION OF COLLISION AVOIDANCE SYSTEM

Numerical simulations assuming several situations of plural ships in collision risk are carried out to confirm validity of the automatic collision avoidance system. Principal particulars of the ships utilized in the numerical simulations are shown in Table 1. They are container ship, VLCC and general cargo ship.

Fig.4 shows simulation results for head-on situation of a container ship (ship 1) with another container ship (ship 2). Ship speed of both ships is 15 knots in this simulation study. Figure (a) display the trajectories of



(a) Head-on situation (b) Crossing situation (c) Overtaking situation

Fig. 3. Location of the virtual ships for each encounter situation

Table 1. Principal dimensions of full scale ships

	Container	VLCC	General Cargo
L (m)	175.0	325.0	155.0
B (m)	25.4	53.0	26.0
d (m)	9.5	22.0	8.7
C_b	0.5717	0.831	0.697

the center of gravity of both ships and positions in every 300 minutes. Solid lines and broken lines indicate the blocking area and the watching area of both ships respectively. Figure (b) shows ratio of overlapping area of the blocking area to the blocking area of own ship denoted with O_{B1} and ratio of overlapping area of the watching area to the watching area of own ship denoted with O_{W1} for ship 1 and figure (c) represents overlapping ratio O_{B2} and O_{W2} for ship 2. Figure (d) & (e) describe heading angles and rudder angles of ship i, ψ_i & δ_i (i = 1, 2), respectively.

It is shown in Fig.4 (a) that ship 1 and ship 2 are in normal navigation phase at $t = 0$(sec.) because there is no lapped area for the watching area. As time goes by, ratio of overlapped area of the watching area, O_{W1} & O_{W2}, become larger as shown in Fig.4 (b). It is found on figure (a) that the blocking area of both ships has already expanded and they are in evasive navigation phase when $t = 300$(sec.). Ratio of overlapping area of the blocking area, O_{B1} & O_{B2}, are always equal to 0. It means that there are enough distance between both ships and they pass each other safely.

Fig.5 shows simulation results for head-on situation between container ship (ship 1) and VLCC (ship 2). Ship speeds of ship 1 and ship 2 are 15 knots and 12 knots respectively. At the beginning of the simulation study, the watching area of both ships has overlapping area. Threrefore the blocking area in bow domain has already expanded. At $t = 0$(sec.), the watching area of ship 2 is going to invade the blocking area of ship 1. Then it is found that ship 2 starts evasive navigation more first than ship 1 in Fig.5 (e). There is no overlap of the blocking area through the simulation.

Simulation results for crossing situation between VLCC (ship 2) and container ship (ship 1) is shown in Fig.6. Ship speeds of both ships are 16 knots and 12 knots respectively. On this situation, ship 1 is the giveway vessel and ship 2 is the burdened vessel. At the begging of the simulation, both ships had already expand contet of the watching area and are cautious of motion of the ships in circumference. At $t = 170$(sec.), ship 1, the giveway vessel, starts to change her route to avoid collision with ship 2 as shown in figure (d). It is found in figure (b) & (c) that overlapped area exists at about $t = 300$(sec.), but ship 1 could return to her original course safely.

Finally, Fig.7 displays simulation results for overtaking situation. Overtaking ship is a container ship (ship 1) in speed of 17 knots and overtaken ship is a general cargo ship (ship 2) in speed of 10 knots. On this situation, ship 1 shuld change her course and ship 2 must keep her original course. Ship 1 begins evasive motion at $t = 200$(sec.). After ship 1 overtook ship 2 safely, she begins to return to her original course at about $t = 1200$(sec.)

5. CONCLUSION

Automatic collision avoidance system using the concept of the blocking area based on traffic regulation has been developed and validity of the system were examined by numerical simulations. It is expected that this automatic collision avoidance system has the ability to avoid collision from the results of the simulation study.

For further development, we need to introduce the disturbance caused by wind and / or current and land.

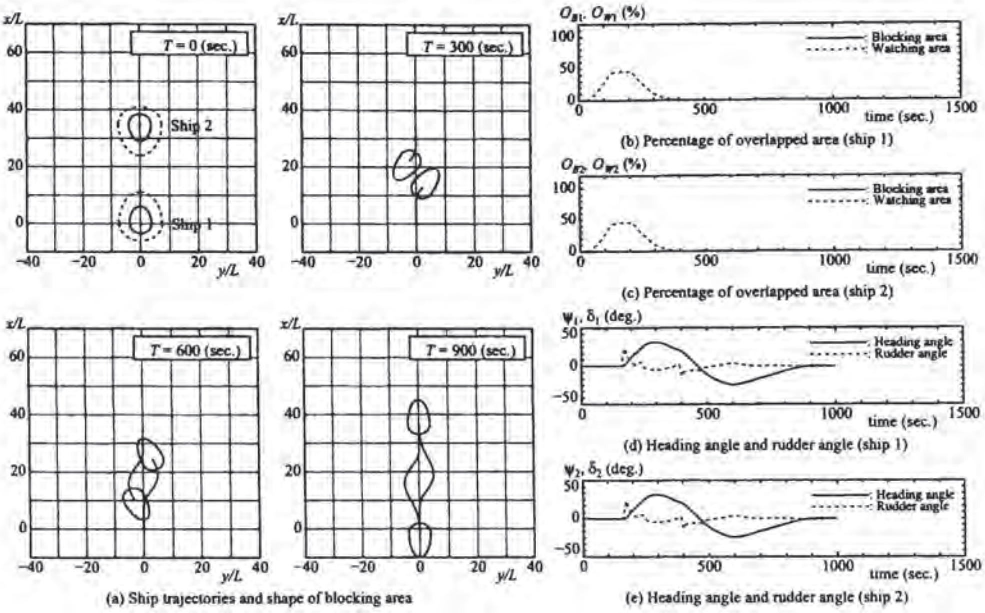


Fig. 4. Head-on situation of container ships ($U_1 = U_2 = 15$kt)

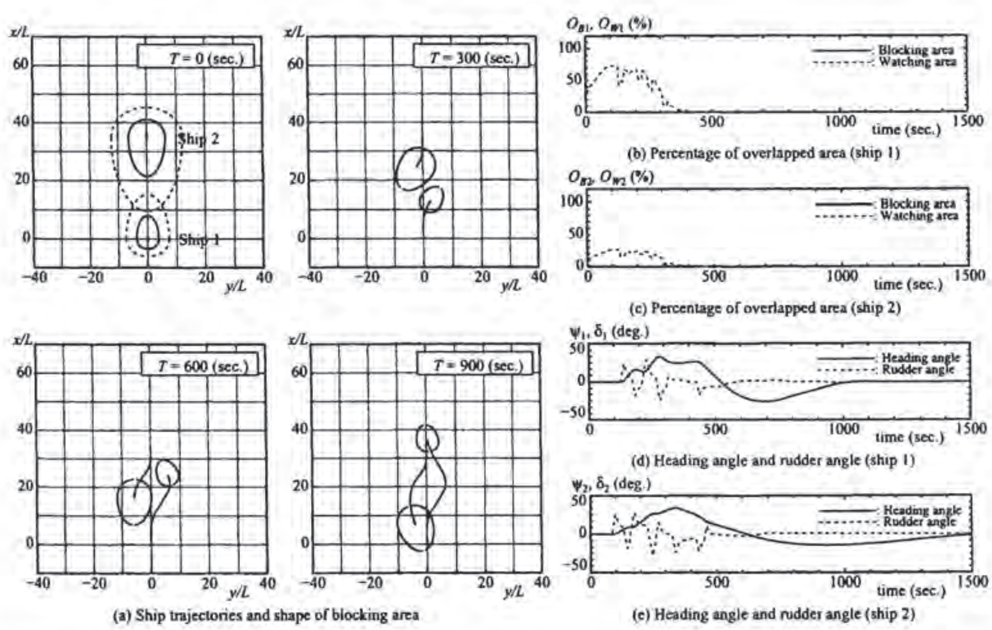


Fig. 5. Head-on situation of container ship & VLCC ($U_1 = 15$kt, $U_2 = 12$kt)

It is desirable that the automatic collision avoidance system can alleviate the burdens of operators under severe conditions and prevent the occurrence of maritime accidents.

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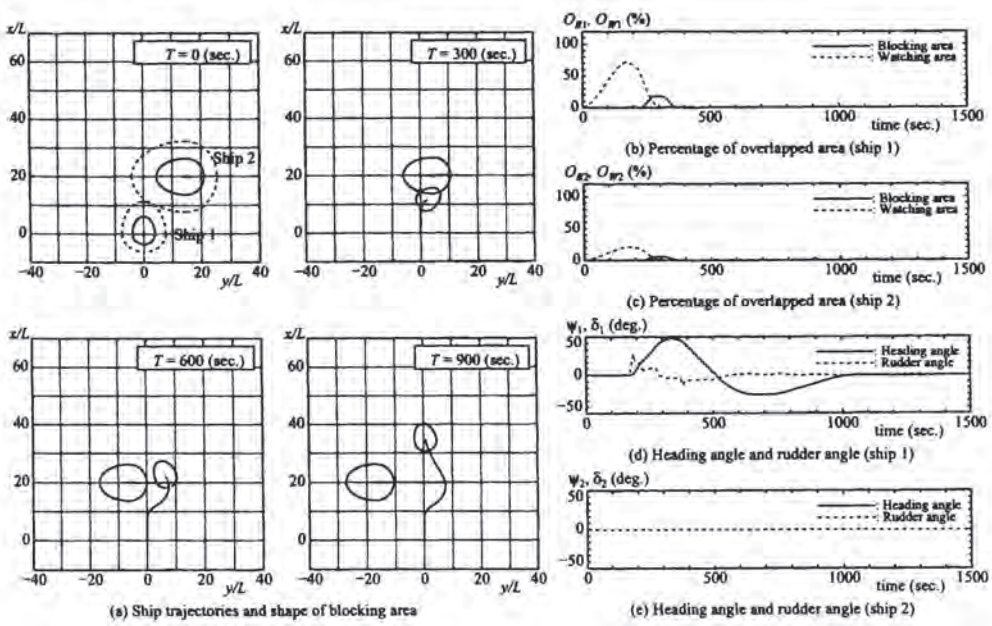

Fig. 6. Crossing situation of container ship & VLCC ($U_1 = 16$kt, $U_2 = 12$kt)

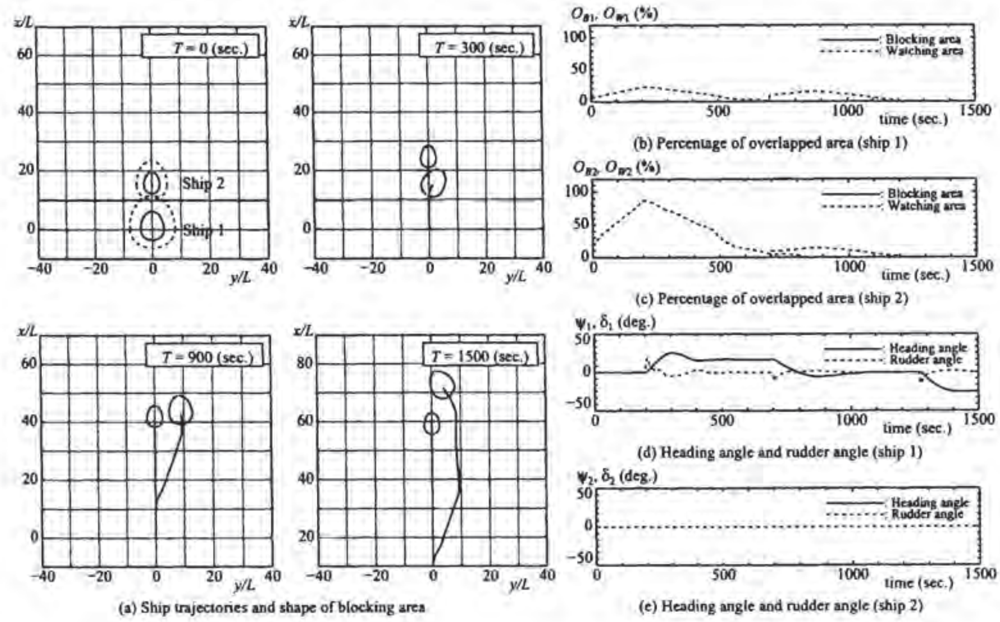

Fig. 7. Overtaking situation of container ship & general cargo ship ($U_1 = 17$kt, $U_2 = 11$kt)

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